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Investigation of Partial Replacement of Fine Aggregates by Crushed Oyster Shells in Concrete Interlocking Paving Block Production

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ABSTRACT

Concrete Interlocking blocks are becoming popular a paving material for pavements, parking areas, rural roads, walk ways, domestic gardens, etc in every part of the world due factors like fast assembly, possibility of easy replacement, enhanced rainwater infiltration, easy handling, fast production, aesthetically pleasing appearance, and availability in wide variety of colors, patterns, models. In the aquaculture industry, oysters are enjoyed as a meal in many parts of the world, the level of consumption and preferred preparations can vary significantly based on regional tastes and culinary traditions. With this global trend, oyster is becoming a popular meal especially in start class hotels in Sri Lanka as well. The shells of oysters, which is the remaining part when it consumes oyster as a meal, are presently disposed to the environment as a waste product. However, various studies have shown the possibility of using crushed oyster shell as fine aggregates for concrete and concrete products. This study has focused on studying usage of crushed oyster shells to partially replace fine aggregates interlocking paving block production through an experimental study. As per results of extensive study done on these aspects, it was found that crushed oyster shells can be used to partially replace fine aggregates in concrete interlocking paving blocks production up to 20% (of weight of fine aggregates) without affecting to desired strength (compressive and flexural strengths) and mechanical characteristics (water absorption, skid resistance, density) of paving blocks.

Keywords: Interlocking Concrete Paving Blocks; oyster shells; fine aggregates; compressive strength; flexural strength;

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1. INTRODUCTION

The demand for paving materials increases day by day as installation of a paving layer for roads, parking areas, pavements, other outdoor areas has become essential for convenience of vehicles and pedestrians in present context. Concrete

interlocking paving blocks are one of the most popular paving materials for above applications especially under light vehicular traffic conditions. Comparatively high infiltration characteristics, attractive appearance, easy maintainability and the

competitive cost of concrete interlocking paving blocks are the main reasons for this popularity.

Scarcity and high cost of raw materials like cement, fine and coarse aggregates have become a major issue for the interlocking paving block production. Especially, scarcity of sand, which is commonly used as fine aggregates for concrete in Sri Lanka, has become a serious concern now in the construction industry, as the Government of Sri Lanka has imposed various regulations to control sand mining considering environmental issues related to sand mining industry. Hence, usage of various alternative materials for above ingredients is continuously being studied by various researcher

s.Oysters are enjoyed as a meal in many parts of the world. It is becoming a popular meal especially in tourist industry, which is one of the main foreign income sources in Sri Lanka. With this context, National Aquatic Resources Research and Development Agency (NARA) of Sri Lanka is

conducting experiments to enhance oyster cultivation in some parts of the country. Oyster shells, which are generated as a waste material when it consumes oyster as meal, are disposed to the environment without utilizing it for any meaningful usage in the local context.

As per a survey done by authors at one of the popular tourist destinations (Negombo area) of the country, the amount of daily disposal of oyster shells by hotels is about 100kg per day. [Figure 1](#) shows disposed oyster shells near lagoon at Negombo and a closeup photograph of an oyster shell. It was noted that this type of disposal would start to cause certain environmental and ecological concerns like blockages of waterways, air pollution (due to emission smell during decomposition), etc. Hence, development of appropriate disposal methodology to effectively utilize disposed oyster is becoming a national need.



Figure 1. Oyster Shells discarded by hotels in Negombo area

Various previous studies (Yoon et al 2003 [1], Kelley 2009 [2], Wang et al 2013 [3], Kuo et al 2013 [4], Abinaya & Prasanna Venkatesh 2016 [5], Garad et al 2019 [6], Jamwal & Kumar 2109 [7], Ubachukwu & Okafor 2020 [8], Ruslan et al 2021 [9], Bunyamin & Mukhlis 2020 [10], Lin et al 2024 [11], Hong & Choudhury 2024 [12], Aye et al 2019 [13]) have highlighted the usage of oyster shell as an substitute to partially replace aggregates and cement (after converting it to powder form) in concrete and concrete related products. Yoon et al 2003 [1] performed Chemical analysis, X-ray diffraction (XRD), specific surface measurement, and micro-structure analysis to study oyster shell properties. The chemical composition indicates that oyster shells

consist predominantly of CaCO_3 (around 96%), with trace amounts of other minerals. Further in this study, the effect of partial replacement of river sand by crushed oyster shells in cement mortar production has been studied. As per results of this study, it was found that dry density of oyster shells is almost equal to river sand and the average particle size of oyster shells is 1.65mm. Further, it has been reported that the practical size of oyster shells is highly influential on strength characteristics of mortar, and drastic reduction of compressive strength of mortar is reported when partial replacement percentage of river sand by oyster shell is more than 40%.

A study done by Ruslan et al 2021 [9] has presented a review about results of various studies done on

usage of crushed oyster shells to partially replace fine aggregates, and usage of oyster shells to partially replace cement in concrete. According to reported results, partial replacement of cement by oyster shell ash (from the percentages of 5% to 20%) lead to considerable reduction compressive strengths. With the partial replacement of fine aggregates by crushed oyster shells, it has reported slight gain of compressive strength when replacement percentage is below 20%. However, workability has gradually reduced with the increment of replacement percentage to 20%.

Accordingly, good potential of using oyster shells for production of concrete can be identified. However, any previous study done on usage of oyster shells as a raw material for production of concrete interlocking paving blocks were not identified. Also, findings of above studies may not be directly applicable for concrete mixes used for interlocking paving block production as various parameters like maximum size of coarse aggregates are controlled when producing concrete for interlocking paving

blocks. Accordingly, this study was focused on investigating the effects on mechanical and physical properties of interlocking paving blocks due to the replacement of fine aggregates by crushed oyster shells and the identification of optimum mix proportions of crushed oyster shell as fine aggregate for interlocking paving blocks based on experimental results. This would provide an opportunity to effectively utilize discarded oyster shells, which is becoming an environment and social concern in certain areas of the country, in a sustainable manner.

It was decided to partially replace fine aggregates only by crushed oyster shells instead of partially replacing cement by oyster shells powder considering energy and cost associated with the second option. In case of partially replacing cement, preheating (above 20000C) and crushing into powder form is essential to achieve cementitious properties as per previous studies [11]. In case of such approach, financial and sustainability benefits expected in this study may become questionable.

2. METHODOLOGY

There are various strength classes for interlocking paving blocks as per Sri Lankan standard (SLS 1425- Part I :2011[14]) for concrete interlocking paving block production. These strength classes with relevant characteristics are presented in [Table 1](#).

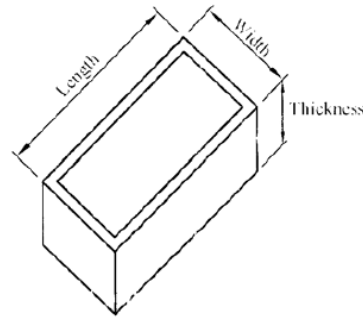
Usually, Class C is the most commonly used strength class in the country for the production of interlocking paving blocks in industrial level as such interlocking paving blocks would possible to be used for roads and pathways subjected to traffic of traffic class T4 (1.5 x 10⁶-3.0x10⁶ ESA-Equivalent Standard Axel).

Table 1. Strength classes of paving blocks as SLS 1425- Part I :2011 [14]

Strength Class	Compressive strength (N/mm ²)		Block Thickness (mm)
	Average	Individual	
1-Class A	50	40	80,100
2-Class B	40	32	80,100
3-Class C	30	25	80,100
4-Foot paths	15	12	60

Hence, this study was also focused on strength class C. SLS 1425- Part I :2011 [14] discusses various possible shapes of the interlocking paving blocks as well. However, most commonly used type is

rectangular shape blocks, and recommended shape and dimensions as per SLS 1425- Part I :2011 [14] for this type is shown in [Figure 2](#) and [Table 2](#) respectively.



Rectangular (R)

Figure 2. Typical shape of a rectangular interlocking paving block**Table 2.** Specified dimensions for rectangular interlocking paving block

Type	Length (mm)	Width (mm)	Thickness
R1	200	100	As per strength class

Accordingly, the rectangular block size having size of 200 mm x 100 mm x 80 mm was selected for this experimental investigation. Based on the DoE (Department of Environment, UK) method and the design approach adopted in Baskaran & Gobinath 2013 [15] and Sampath & Gunathilake 2024 [16], the mix design was developed to comply with the strength class 3. The maximum size of coarse

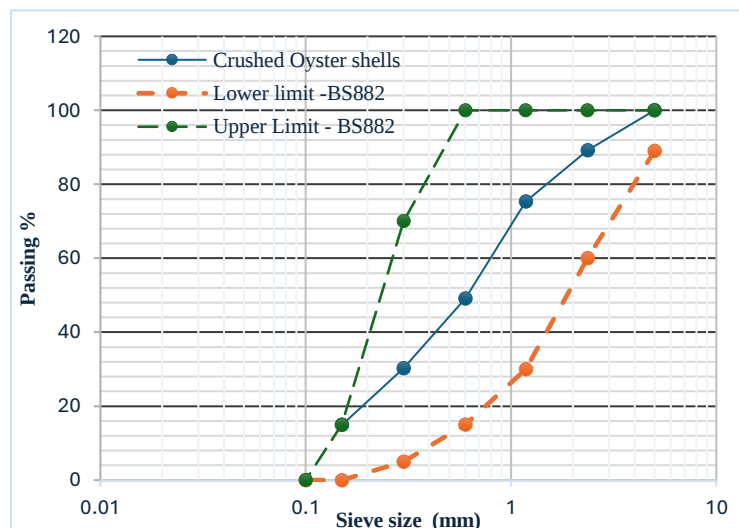
aggregates was limited to the 12mm as specified in Indian standard for IS 15658:2006 [17] even though such limit is not specified in SLS 1425- Part I :2011[14]. Further, the maximum size of coarse aggregates is limited to the same size range in the present industrial practice in the county as well when commercially producing interlocking blocks. The developed mix design is given in Table 3.

Table 3. Mix proportions as per the developed mix design

Water Cement Ratio	Cement (kg/m ³)	Fine aggregates (kg/m ³)	Coarse aggregate (kg/m ³)
0.54	348.8	706.5	1193.2

As this study was focused on partial replacement of fine aggregates by crushed oyster shells, collected oyster shells were washed using clean water and allowed to dry for 48 hours. Subsequently, those

were crushed using a conventional metal crusher. Subsequently, sieve analysis was performed for crushed oyster shells as per BS 882 [18] and it was presented in Figure 3.

**Figure 3.** Sieve analysis results of crushed oyster shells

For the comparison of results, a sieve analysis of conventional fine aggregates (river sand) was also

performed and presented in [Figure 4](#).

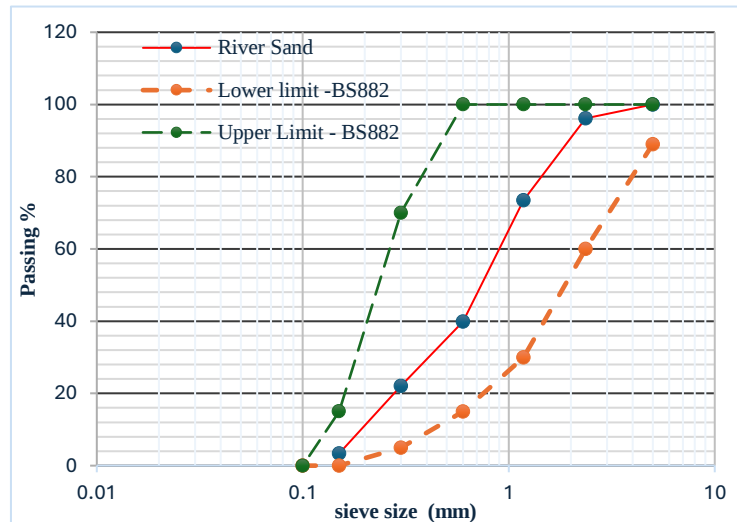


Figure 4. Sieve analysis results of river sand

As per [Figure 3](#) and [4](#), it is evident that number of fine particles are considerably high in crushed oyster shells as percentage passing through 0.15 mm sieve is high as 14.91%. Which is almost equal to the upper limit (15%) specified in BS 882 [\[18\]](#). However, crushed oyster shells still remain within limits specified in BS 882 [\[18\]](#) for fine aggregates. Considering this observation and findings of previous studies, it was decided to consider wherever

conventional fine aggregates are replaced by crushed oyster shells in percentages (w/w) of 10%, 20%, 30% and 40% in addition the control sample where only conventional fine aggregates (river sand) were used. Sieve analysis tests were reperformed individually for prepared samples after replacing sand by above percentages of crushed oyster shells, and results are presented in [Figure 5](#).

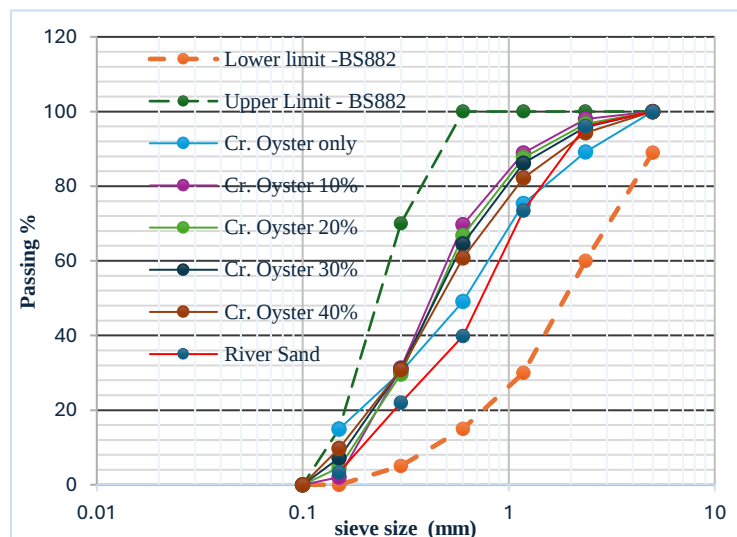


Figure 5. Sieve analysis results of fine aggregates with considered partial replacement percentages

It can be clearly noted that all of above partial replaced samples, where river sand was replaced by oyster shell by respective percentages lie within the limits of BS 882 [\[18\]](#).

As this study was mainly focused on investigating the effects on mechanical and physical properties

interlocking paving blocks due to replacement of fine aggregates by crushed oyster shells, mix proportions listed in [Table 4](#) were selected for casting of concrete interlocking paving blocks for the experimental study.

Table 4. Mix proportions considered for the experimental study

Type	Oyster shells %	Water Cement Ratio	Cement (kg/m ³)	Oyster shell (kg/)	Sand (kg/m ³)	Coarse Agg. (kg/m ³)
Control sample	0 %	0.54	348.8	0	706.5	1193.2
10% Oyster	10 %	0.54	348.8	70.65	635.85	1193.2
20% Oyster	20 %	0.54	348.8	141.3	565.2	1193.2
30% Oyster	30 %	0.54	348.8	211.95	494.55	1193.2
40% Oyster	40 %	0.54	348.8	282.6	423.9	1193.2

As per a common industrial practice at certain sites, the concrete for production of interlocking paving blocks was developed by hand mixing. However, proportion of all ingredients of each mix was strictly maintained as per quantities mentioned in [Table 4](#). Slumps of all mixes were checked prior to casting. The casting of interlocking paving blocks was done using plastic mold of standard sizes. A layer of

lubricant oil was coated on the inner surface of the mold for the ease of demolding before casting. The concrete interlocking paving blocks were demolded after 24 hours and cured in a tank until specific dates for respective mechanical and physical test. Photographs taken during casting of blocks are presented [Figure 6](#).

**Figure 6.** Casting of interlocking paving blocks for the study

3. RESULTS AND DISCUSSION

As already discussed, the workability of each considered mix was checked using the standard slump test to check the effect of partial replacement of sand by crushed oyster shells on workability. Results of slump test are presented in graphical form in [Figure 7](#). According to the results, the slump values range from 21mm to 28mm. The minimum slump of 21mm was reported relevant to the mix containing 40% of crushed oyster shells instead of river sand as presented in [Figure 7](#). Conversely,

the maximum slump of 28 mm is observed in the control mix. This observation is compatible with observations highlighted in the literature. As per Wang et al 2003 [3] and Hong & Choudhury 2024 [12], the reduction of workability of mortar has been observed when crushed oyster shells is used as fine aggregates. The increase of interparticle friction due to integration of irregular particle shaped of crushed oyster shells would be the probable reasons for this observation as per Wang et al 2003 [3].

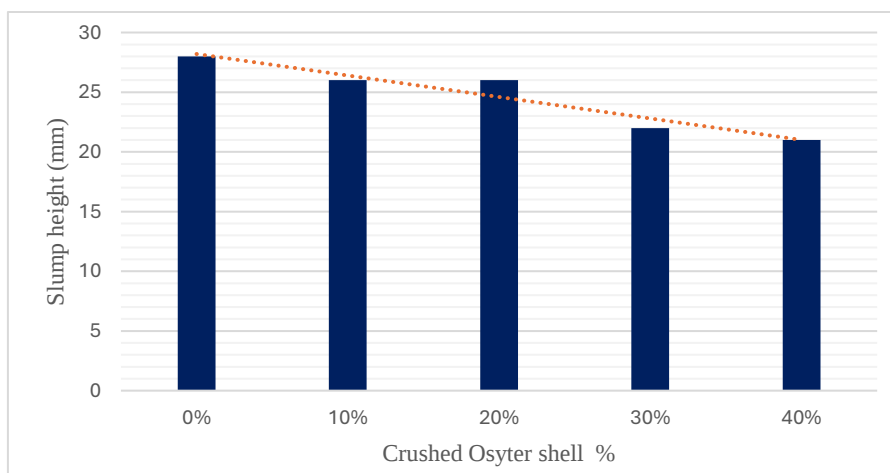


Figure 7. The variation of slump height

As per SLS 1425- Part I :2011 [14], the compressive strength of blocks is the main mechanical property that would be checked for compliance. Accordingly, compressive strengths of interlocking paving blocks

were checked at 7 days and 28 days as per the standard procedure of mentioned in the standard. The test set up used for the testing is presented [Figure 8](#).



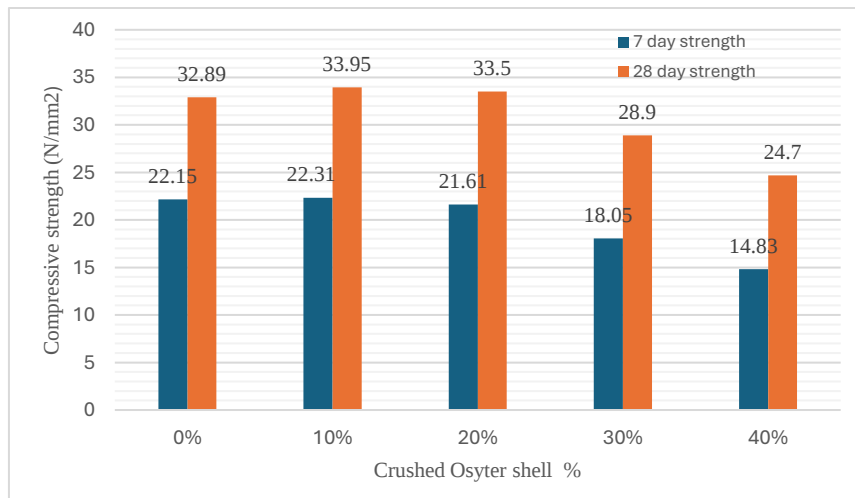
Figure 8. Test setup used for the compressive strength tests

Three samples of each type were tested, and test results of samples are presented in [Table 5](#).

Table 5. Compressive strength results of blocks

Sam. No	oyster %	Compressive Strength (N/mm ²)		Average Compressive Strength (N/mm ²)	
		7 Days	28 Days	7 Days	28 Days
S1	0	21.95	31.05	22.15	32.89
S2		21.7	33.77		
S3		22.8	33.85		
S4	10	18.05	29.32	22.31	33.95
S5		24.8	36.85		
S6		24.1	35.7		
S7	20	24.8	36.7	21.61	33.5
S8		22.15	31.6		
S9		17.9	32.2		
S10	30	18.45	30.4	18.05	28.9
S11		19.1	31.1		
S12		16.6	25.2		
S13	40	15.2	23.65	14.83	24.7
S14		13.2	30.25		
S15		16.1	20.2		

Same results are presented in graphical form in [Figure 9](#).

**Figure 9.** Compressive strength results at 7 days and 28 days in graphical form

As it can clearly observed in [Table 5](#) and [Figure 9](#), the highest average compressive strengths at both 7 days and 28 days were observed when crushed oyster shell percentage was 10%. The highest average compressive strengths at 7 days and 28 days are 4% and 3% higher than the same of control samples respectively. When increasing the partial replacement percentages of sand by crushed oyster shells more than 10% both average compressive strengths have started to decline. Especially, when partial replacement percentage is more than 30%, a

drastic reduction of compressive strengths can be observed. As reported by Kuo et al 2013[4], the inclusion of crushed oyster shell at small percentage may be able to fill the voids in concrete resulting in strength gain observed up to 10% replacement. Presence of calcium carbonate (CaCO₃) as main constituent in oyster shells may have also contributed to this strength gain. However, even with 20% replacement, the reduction of compressive strength is marginal.

Nevertheless, when the percentage replacement is further increased, undesired characteristics of oyster shells like higher water absorption capacity, presence of large number of finer particles, etc may have caused a negative impact on compressive strengths of interlocking paving blocks resulting in reduction of compressive strength as it can be observed in [Figure 9](#).

Even though the local standard for interlocking paving blocks does not discuss flexural strength of blocks, most other international codes discussed checking of flexural strength too for compliances.

This is understandable as interlocking paving blocks may be subjected to flexural stresses in real usage of them due to unevenness of bedding layers, local settlements of soils, etc. In fact, SLS 1425 - Part I :2011 [[14](#)] also indicated the intension of incorporation of flexure and splitting tensile strength related testing in its future revisions. Accordingly, it was decided to carry out flexural strength tests of these samples as per Indian Standard for interlocking paving blocks. The test setup developed in this regard is presented in [Figure 10](#).



Figure 10. Test setup used for the flexural strength tests

As per IS 15658:2006 [[17](#)], flexural strengths of blocks were calculated as per the formula presented below.

$$f = \frac{3Pl}{2bd^2}$$

- f = Flexural Strength, in N/mm²;
P = Maximum load, in N;
l = Distance between central lines of supporting rollers, in mm;
b = Average width of block, in mm;
d = Average thickness, in mm.

Results of the test in tabulated form and graphical form are presented in [Table 6](#) and [Figure 11](#) respectively.

Table 6. Flexural strength results of block

Sample no.	Oyster %	Flexural strength (N/mm ²)	Average flexural strength (N/mm ²)
S1	0%	6.768	7.517
S2		7.242	
S3		8.542	
S4	10%	7.953	7.648
S5		7.867	
S6		7.125	
S7	20%	7.998	7.659
S8		7.725	

S9		7.254	
S10		3.87	
S11	30%	6.412	6.505
S12		6.598	
S13		3.285	
S14	40%	4.47	4.623
S15		4.776	

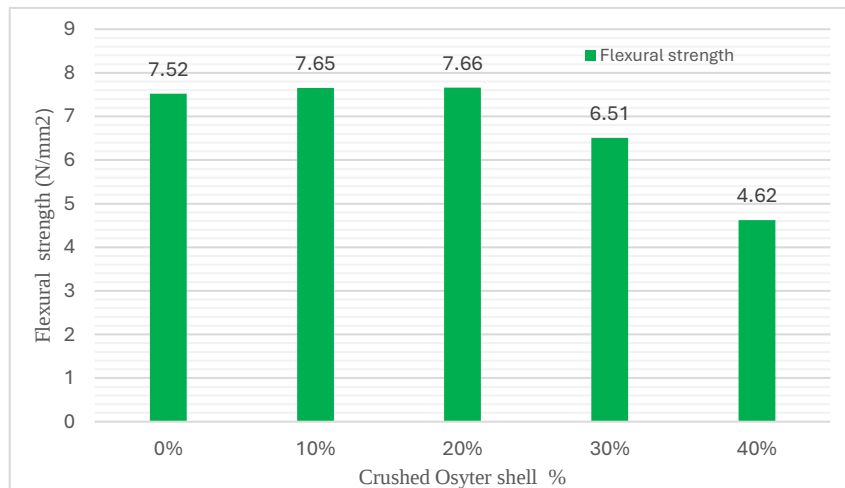


Figure 11. Flexural strength results in graphical form

In case of average flexural strengths, the highest average flexural strength was reported when partial replacement percentage is 20%. However, it was only a 2% increase from the average flexural strengths of control samples. A drastic reduction of flexural strengths was observed when partial replacement percentage is more than or equal to 30%. Similar variations of flexural and tensile strengths have been reported by Jamwal & Kumar 2109 [7] in their study. Effects of already highlighted undesired characteristics of crushed oyster shells like higher water absorption capacity, presence of large number

of finer particles, etc would be the probable reasons for the flexural strength reduction when partial replacement percentage is higher than 20%.

In addition to strength tests, the water absorption and dry density of blocks were also investigated for considered crushed oyster shell percentages. As per SLS 1425- Part I :2011 [14], the water absorption percentage should be maintained below 6% and no limit relevant to dry density is not being specified. Figure 12 and 13 present results of water absorption and dry density test of interlocking paving blocks in graphical form respectively.

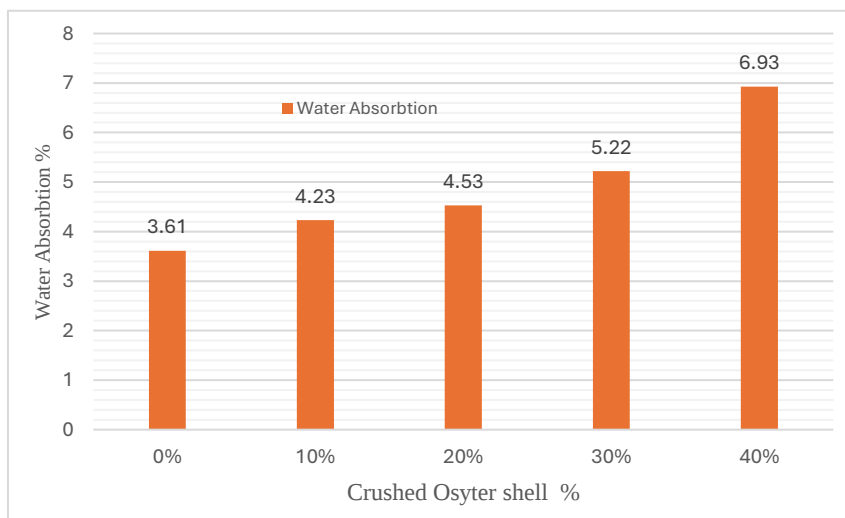


Figure 12. Water absorption results of blocks in graphical form

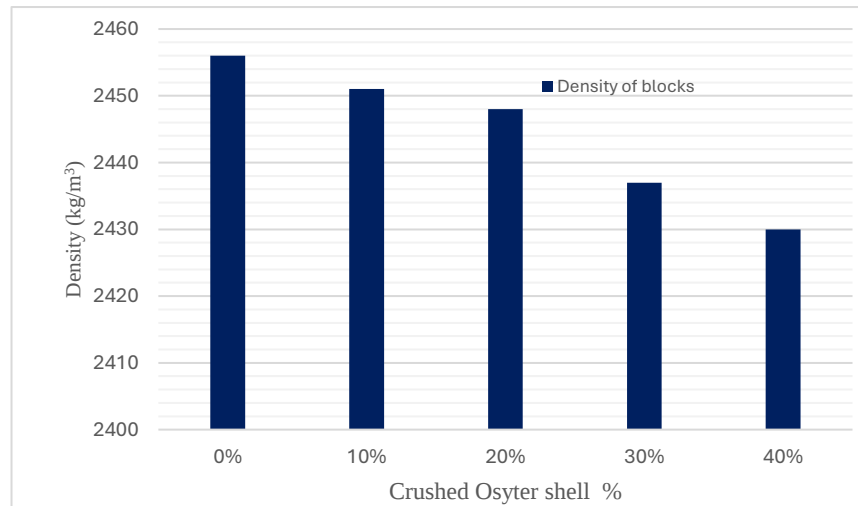


Figure 13. Density results of blocks in graphical form

As per results, all partial replacement percentages except 40% case have satisfied the water absorption criteria specified in the local standard. Further, it was observed trends of increase of water absorption and decrease of density with the increase of partial replacement of sand by crushed oyster shell as it can be visualized in [Figure 12](#) and [13](#) respectively. The porous nature of CaCO_3 , which is the main ingredient of oyster shells (as reported by Yoon et al 2003 [1]) would be the main probable reason for these observations.

Skid resistance of surfaces of interlocking paving blocks depends on a surface's micro texture and

macrotexture. Skid resistance is the force developed when a tire that is prevented from rotating slides along the pavement surface. Skid resistance is generally quantified using some form of friction measurement such as a friction factor or skid number. SLS 1425- Part I :2011 [14] has specified a minimum USRV (Unpolished Slip Resistance Value) of 55 for interlocking paving blocks. Accordingly, it was conducted standard USRV tests as per above the standard for sample set 1 (control sample set) and sample set 3 (20% crushed oyster shell set). The results are presented in [Table 7](#).

Table 7. Skid resistance results of interlocking blocks

Oyster shells replace. %	Side	Test readings (USRV)			Testing Temp. (°C)	Mean USRV of both side
		3 rd	4 th	5 th		
0%	1 st side	55	55	55	28	55
	Oppo. side	55	55	50	28	
20%	1 st side	55	55	55	28	55
	Oppo.side	55	55	55	28	

According to results, both control sample set and set with 20% crushed oyster shells have shown the same mean USRV as presented in [Table 7](#). Both sets complied with the requirement given in SLS 1425- Part I :2011[14], as both sets showed USRV of 55, which is the minimum acceptable value as per the standard.

Considering both non mechanical and mechanical test results, replacement of fine aggregates up to 20%

by crushed oyster shells was selected as the best scenario as it would provide a better financial benefit as well. Accordingly, comparative financial analysis of samples having 20% replacement percentage and control samples were performed based on present local material and labor prices. In the analysis, a purchasing price for oyster shells was not considered as it is freely available as a waste material. However, costs for crushing operation and transportation were

considered for it in the analysis. The reported financial saving was only 1.5% as per the results of the analysis. Even though this is minimal value in financial terms, usage of oyster shell for this application would provide a good solution for

4. CONCLUSIONS

The main aim of this research was investigating the possibility of partial substitution of sand by crushed oyster shells in interlocking paving block production and identification of optimum percentage of partial replacement through an experiment study. This research revealed substantial insights into the performance of interlocking blocks when crushed oyster shells was utilized as a partial substitute for fine aggregates. According to sieve analysis tests, Crushed Oyster Shells demonstrated a suitable particle size distribution that aligns with the requirements for fine aggregates for concrete production especially when it is mixed with sand (up to 40%). Based on this observation, crushed oyster shell was used to replace sand by percentages varying from 10% to 40%. As per results, even though the workability was affected by crushed oyster shell percentage, drastic reduction of workability was not observed up to 20% replacement. In terms of compressive strengths (both early age and final strength) increments (percent increments of early age strength and final strength were 3% and 4% respectively) were observed until the replacement percentage is reached to 10%. Even with 20% of crushed oyster shells, drastic reduction of compressive strength was not observed. Flexural

managing oyster shell waste in an effective manner as it can become a socio environmental concern in near future for certain areas of the country. Further, it will be some form of solution for shortage of sand experienced by the industry in the present context.

strength increment was observed until replacement percentage reaches 20% (percentage increment is about 2%).

Even though replacement of sand by crushed oyster shells made a negative impact for water absorption and dry density, acceptable results were observed up to the replacement percentage of 30%. Abrasion resistance results were also indicated acceptable results for the 20% replaced samples. Accordingly, it was identified that the best replacement percentage of sand by crushed oyster shells would be 20%.

As per the financial analysis performed relevant to 20% replacement percentage, slight financial gain of about 1.5% was noted.

Hence, usage of crushed oyster shells to partially replace sand in concrete interlocking paving block production could be recommended up to 20%. However, direct financial benefit in terms of this replacement is not significant as per the financial analysis. Nevertheless, this proposed approach would facilitate the effective management of oyster shells, which is a waste product generated during consumption of oysters as a meal, and reduction of river sand requirement for production of concrete interlocking blocks. Hence, this would be beneficial in sustainable development perspective as well.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interest with respect to the authorship and/or publication of this paper.

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